21. Monitoring of the remobilisation of the May Ntebteb landslide near Hagere Selam

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Introduction

During the last decade, slope failures were reported in a 500 km^2 study area in the region of Hagere Selam, Mekelle, northern Ethiopia (Nyssen et al., 2002; Tesfahunegn, 2008; Moeyersons et al., 2008; Van Den Eeckhaut et al., 2009; Shimelies, 2009) (Fig. 1).

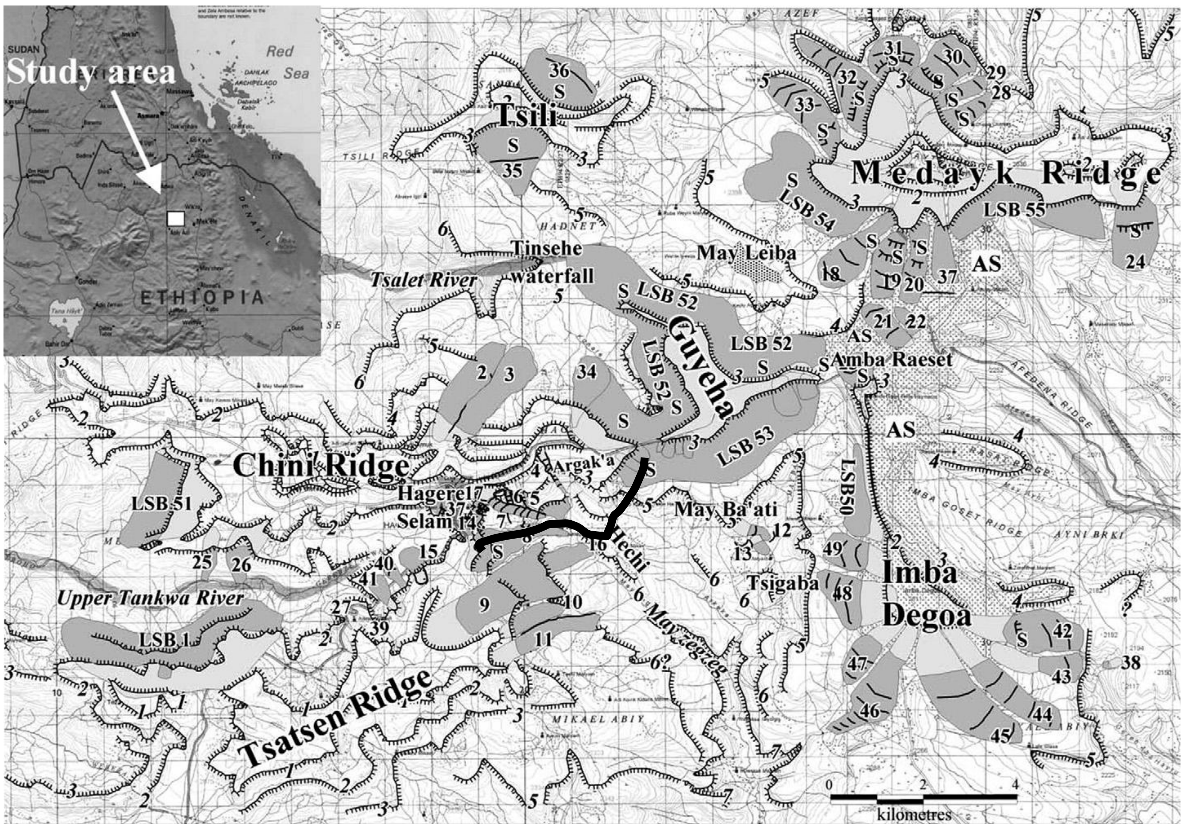

Fig. 1. Location of the study area and distribution of landslides. Landslides and landslide belts (LSB) in grey are numbered. Light grey: erosional or source area; dark grey: depositional area, accumulation lobe. Barbed lines represent cliffs. The light grey zone indicated by AS gives the extension of Agula shales based on Bosellini et al. (1997). Thick line represents the transect walk. Observation point is at the toe (southern edge) of landslide 4 (After Moeyersons et al., 2008).

The majority of the landslides are old debris flows, affecting the plateau basalts and flowing over the plateau edge, producing a sometimes km-long landslide foot, covering the steep plateau escarpment and often reaching the plain 200 to 400 m lower. For a limited number of these landslides reactivations were reported endangering roads and other infrastructure. One of these reactivations concerned the Amba Raeset debris flow in 1999 (see section 14). Nyssen et al.

(2002) attribute the general tendency of reactivation of landslides in the region to changes in land use which contribute to a general increase in the soil water content (i.e. soil and water conservation measures such as conversion of rangeland into exclosures). This decreases the values of the apparent cohesion and of the angle of internal friction and can eventually lead to an increase of the hydrostatic pressures at the base of the landslide.

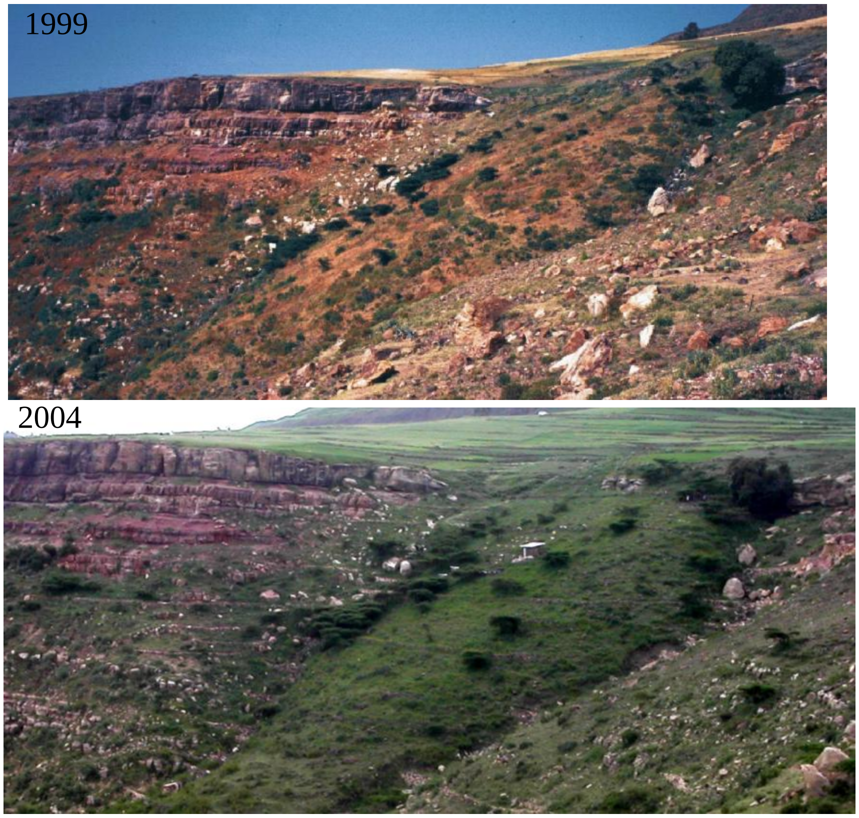

Fig. 2: The May Ntebteb flow in 1999 (top) and in 2004 (bottom), provided with several stone bunds.

The land use changes on the May Ntebteb flow (Fig. 1, landslide 4) in 2002-2004 were a unique occasion to test the hypothesis that the installation of stone bunds on the landslide lobe (Fig. 2) and the consequent increase of water infiltration into the soil (Nyssen et al., 2004) resulted in an increasing landslide activity. The displacement of the flow has been monitored between October 1998 and March 2001 (Nyssen et al., 2002). This note discusses the result of a ongoing monitoring campaign which started in 2007.

Materials and methods

The study area

The study area (Fig. 1) is located in Tigray, northern Ethiopia, and covers a 500 km^2 rectangle in the watershed of the Geba and Werei river basins east and north of Hagere Selam, some 50 km west of Mekelle. The area was chosen because it reveals a complete geological section with Paleozoic and Mesozoic sandstones, carbonates and limestones overlain by Tertiary basalts (Fig. 3). Especially the latter are believed to be prone to slope failure. The present-day, structural landscape of tabular, stepped ridges of Tsatsen (2912 m a.s.l.), Chini (2757 m a.s.l.), Guyeha (2600 m a.s.l.), Tsili (2700 m a.s.l.), Medayk (2835 m a.s.l.), and Imba Degoa–Amba Raeset (2611 m a.s.l.) is resulting from differential erosion of the subhorizontal and monoclinal lithological layers. Between these ridges there are several hundred meter deep valleys. The occurrence of cliffs and steep escarpments is typical.

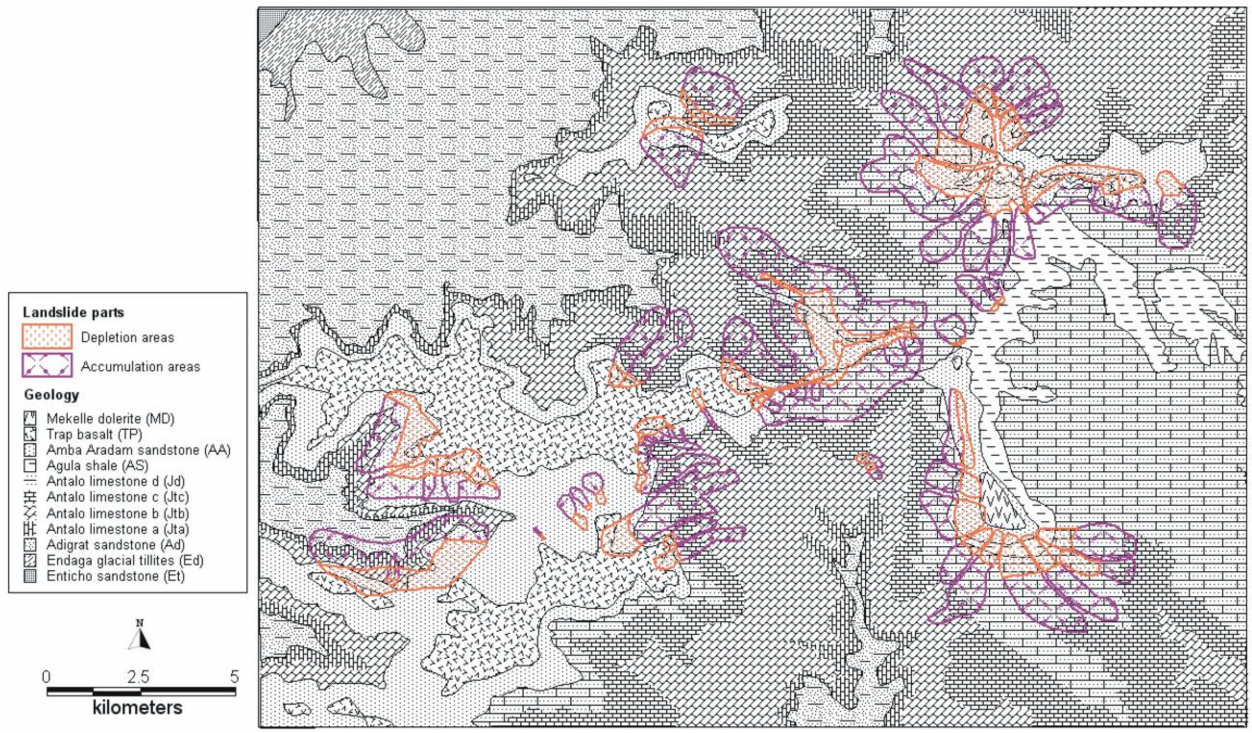

Fig. 3. Geological map of the study area (after Russo et al., 1999) with overlay of landslide depletion and landslide accumulation areas (Van Den Eeckhaut et al., 2009).

The oldest geological formation in the study area, deep in the valleys of the May Zeg-zeg, Tsaliet and upper Tankwa rivers is the Upper-Palaeozoic Adigrat sandstone. It is overlain by marine Antalo limestones of Jurassic age, about 500 m thick. Agula shales, which form the upper part of the Antalo supersequence (Bosellini et al., 1997) are present in a small belt around the Imba Degoa–Amba Raeset and on the elongated pass between the latter and the Medayk Ridge (Fig. 1; 3). Agula shales, where present, or Antalo limestones are truncated by a peneplanation disconformity (see section 28), overlain by Amba Aradam sandstone of Cretaceous age and by two series of Tertiary basalt. The latter are separated by partially silicified lacustrine deposits. The base and lower part of most ridges in the study area typically display outcrops of the Antalo supersequence, mostly only Antalo limestones, often in the form of massive limestone cliffs. The Amba Aradam sandstone and the tertiary basalts form the tabular extensions on top of the ridges, table mountains or plateaux.

The May Ntebteb flow is a recently reactivated ancient debris flow (Fig. 1, landslide 4). It has an affected area of 0.11 km^2 (with a length of 1100 m and a width of 100 m) and a displaced volume estimated at 1.7 10^6 m^3. The depletion and accumulation area have a slope of 52 and 13% respectively (Nyssen et al., 2002). The drainage channels that developed on both landslide boundaries are typical for old landslides.

The measuring method

To investigate the displacement of the May Ntebteb flow a network of measuring points was installed on and around the flow and measured with a laser theodolite. Amba Aradam sandstone boulders and rock fragments of dimensions of decimeters to meters were used as marker points. Only blocks which are for their major part embedded have been used so that rock creep over the surface can be excluded as possible source of error. Hence, the movement rate of the blocks is suggested to represent the movement rate of the landslide debris, which mainly consists of swelling clays resulting from the weathering of the plateau basalts. In April 2007, 45 measuring points were selected (Fig. 4). Three fixed reference points, A, B, and C upslope of the main scarp were used to put up a local coordinate system. Within the landslide-affected area 36 measuring points were marked and 6 measuring points were selected a few meters outside the landslide affected area in order to verify that the flow indeed moves faster than the surrounding sediment slopes. All measuring points were holes in rocks made by means of a chisel and indicated with paint (Fig. 5).

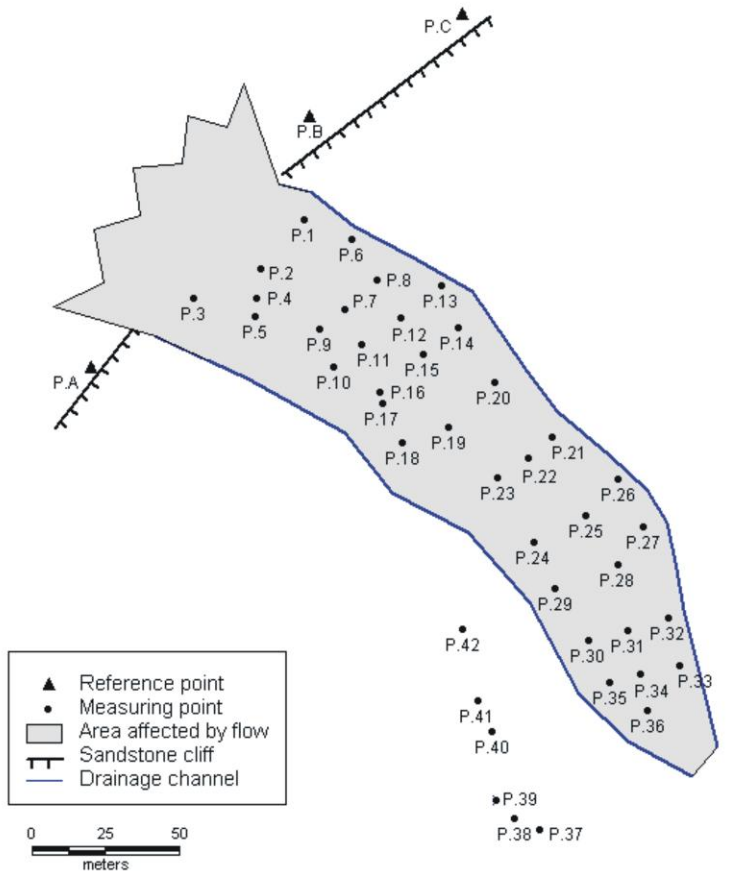

Fig. 4: Distribution of the marked blocks with a schematic representation of the sandstone cliff, area affected by the debris flow and drainage channels. Slope direction is to the South-east.

The same monitoring technique has been used during the period October 1998 - March 2001 (Nyssen et al., 2002), but the blocks were arranged on one line along the central axis of the lobe. This line extended for 83 m downslope from the cliff. The measurements which started in 2007 used much more block points, enabling a distinction of the spatial variability of the movement.

Fig. 5: Example of marker point

Provisional results

Till now there has only been done one reading of the displacement of the 45 blocks, in the middle of August 2008. Table 1 shows some results, but they have to be interpreted with care. The points outside the landslide-affected area clearly show less displacement compared to the points inside the landslide. For the six uppermost points, which cover about the 50 upper meters of the lobe, the mean displacement was 6.7 cm in the downslope direction. Compared with the displacement measured between October 1998 and March 2001, estimated at 6.4 cm in the 83 upper meter of the lobe (Nyssen et al., 2002), we measured an increase (doubling) of the creep rate. This might strengthen the hypothesis that the change in soil use (Fig. 2) on the lobe and in the upslope contributing area influences positively the creep rate.

The 2008 measurements also suggest differential movement within the debris flow. For the more downslope points the displacement was generally lower (average 3.7 cm) but not always in the downslope direction only and hence these points are more difficult to interpret. It can be deduced that the acceleration in the movement starts upslope, where slopes are steeper, and decreases in downslope direction causing compression and pressure increase in the middle part of the lobe. However, future measurements are required to confirm whether this is a continuous trend.

Table 1: Displacement measured between August 2008 and April 2007

	Reference points	Point in affected area		Point outsided affected area
	(PA-C)	P1-6	P7-36*	P37-42
Mean	0.006	0.067	0.037	0.014
Stdev	0.002	0.039	0.014	0.009

* For P7-36 the measured displacement was not always in the downslope direction.

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